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**ILLUMINANCE AND LUMINANCE DISTRIBUTIONS OF A  
PROTOTYPE AMBIENT ILLUMINATION SYSTEM FOR  
SPACE STATION *FREEDOM***

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Mission Operations Laboratory  
Science and Engineering Directorate

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## TECHNICAL MEMORANDUM

# ILLUMINANCE AND LUMINANCE DISTRIBUTIONS OF A PROTOTYPE AMBIENT ILLUMINATION SYSTEM FOR SPACE STATION *FREEDOM*

## INTRODUCTION

One of the key variables in assessing the impact of environmental factors on the physiological and psychological health of the crew, as well as the influence on productivity, is mission duration. In space, as on Earth, the importance of habitability factors increases with extensions in mission or task duration [1]. There is a significant difference between the human ability to adapt to environmental stresses to accomplish a successful 5- to 10-day mission and for a 120-day or longer mission. To meet this challenge, the designers and contractors of Space Station *Freedom* must be responsive to human habitability to a degree unprecedented in the history of NASA.

This report represents the results of an initial investigation of the human factors and habitability issues raised by possible lighting configurations employed for long duration missions such as those proposed for the space station. Preliminary results of research at Pennsylvania State University in the late 1970's (Flynn, ref. 2) suggest that perceptual qualities of an enclosure can be influenced by the pattern of luminance within the space. Subjective impressions such as spaciousness, perceptual clarity, relaxation or tension, and public or private enclosures, among others, appear to be related to different combinations of surface luminance distributions. For example, the use of multidimensional scaling to analyze test subject responses indicates uniform peripheral illumination produces a greater impression of spaciousness than nonuniform overhead illumination [2].

The primary lighting concept evaluated in this study, the differentiation between task and ambient illumination requirements, is common to many Earth-bound work environments. Spurred by concerns with energy efficiency and an increased emphasis on human factors in design solutions, engineers have provided illumination systems to delineate this distinction since the mid-1970's. With this concept, the ambient lighting system provides the lower level illumination necessary to maintain spatial orientation, to safely traverse an enclosure, to accomplish routine visual tasks for which speed and accuracy are not critical, and to provide luminance distributions that promote psychological well-being [3]. This is augmented by task lighting, a system to provide greater levels of illumination for workstations and task locations that is tailored to meet the needs of specific visual tasks. The focus of the current investigation is on the ambient illumination component of this system only.

Specific light source selection and space-qualified hardware design issues have been intentionally avoided to focus on the implications of the illuminance and luminance distributions of several possible ambient lighting configurations. A prototype indirect ambient illumination system was developed which will allow crew members to alter surface luminance and illuminance distributions within an enclosed module, thus enabling them to modify perceptual cues to match crew preferences. A direct ambient illumination system was compared to the prototype utilizing the full-scale mockup of Space Station *Freedom* developed by Marshall Space Flight Center (MSFC). The

traditional direct lensed system was installed in the habitation (HAB) module, with the indirect prototype deployed in the U.S. laboratory (LAB) module. While the effects of discomfort glare, veiling reflections, color temperature, color rendering, and spectral power distribution were considered in the design and fabrication of prototype luminaires, the analysis of these variables remains beyond the scope of present work.

The luminaires in both the HAB and LAB modules were assembled from readily available inexpensive components to meet demanding delivery schedules. While the direct lensed luminaires in the HAB module were fabricated from a single concept drawing, the indirect LAB system is the product of a short prototype development study [4], where a single luminaire was analyzed and modified several times prior to final production and installation throughout the module (fig. 1).

After the completion of the mockup, it became apparent that subsequent lighting investigation should respond to the successes and failures of these first design concepts. The authors initiated a concerted data gathering effort with the goal of establishing an illuminance and luminance data base. While this will have obvious value as a comparative reference for future lighting studies, the analysis and interpretation of this data is the task of this initial investigation. The objectives are:

1. Comparison of direct and indirect ambient lighting systems
2. Comparison of various luminaire spacings within modules
3. Comparison of these ambient lighting test configurations and the performance specifications outlined in volume IV of NASA Standard 3000, "Man-Systems Integration Standards" (MSIS) [5].

## DEFINITIONS

Illuminance: Light falling on a surface or the density of the luminous flux incident on a surface. When a surface is uniformly illuminated, it is the quotient of the luminous flux divided by the area of the surface.

Footcandle (fc): The unit of illuminance when the foot is taken as the unit of length. It is the illuminance on a surface 1 ft<sup>2</sup> in area on which there is a uniformly distributed flux of one lumen, or the illuminance produced on the spherical surface of 1-ft radius from a directionally uniform point source of one candela.

Lumen (lm): Unit of luminous flux. Photometrically, it is the luminous flux emitted within a unit solid angle (one steradian) by a point source having a uniform luminous intensity of one candela.

Candela (cd): Unit of luminous intensity. One candela is one lumen per steradian.

Luminance: Light leaving or transmitted through a surface in a given direction. Luminous intensity per unit area measured normal to the given direction.

FootLambert (fL): A unit of luminance equal to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of 1 lm/ft<sup>2</sup>.

Reflectance: The ratio of the reflected flux to the incident flux in reference to a given surface. Measured values of reflectance depend upon the angles of incidence and view as well as on the spectral character of the incident flux.

Luminaire: A light fixture. A complete lighting unit consisting of a light source (lamp) together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

## NOTATIONS

In many of the comparative graphs the following notations are used on the X-axis to delineate the various test configurations:

H1: HAB module direct luminaire spaced every rack.

H2: HAB module direct luminaire spaced every second rack.

H3: HAB module direct luminaire spaced every third rack.

LUD1: LAB module indirect up and downlight component luminaire spaced every rack.

LUD2: LAB module indirect up and downlight component luminaire spaced every second rack.

LUD3: LAB module indirect up and downlight component luminaire spaced every third rack.

LU1: LAB module indirect uplight component luminaire spaced every rack.

LU2: LAB module indirect uplight component luminaire spaced every second rack.

LU3: LAB module indirect uplight component luminaire spaced every third rack.

LD1: LAB module indirect downlight component luminaire spaced every rack.

LD2: LAB module indirect downlight component luminaire spaced every second rack.

LD3: LAB module indirect downlight component luminaire spaced every third rack.

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(A)



(B)



(C)

Figure 1. (A) Installation of reflector assembly in indirect prototype luminaire. (B) Evaluation of the downlight component of a single prototype luminaire. (C) The U.S. Laboratory Module mockup under construction with the first operational production luminaire installed.

## TEST EQUIPMENT

The test modules consisted of the HAB module and the U.S. LAB module, both part of the full-scale mockup of the space station developed at MSFC (fig. 2). Interior dimensions of the modules were identical, with the occupied center volume of each measuring 7-ft high by 7-ft wide by 38.5-ft long, exclusive of end cones. The primary interior surfaces are satin finish paint, with measured ceiling, wall, and floor reflectances of 69, 69, and 26 percent respectively, in the HAB module, and 74, 69, and 26 percent in the LAB module. The rack surfaces in the test areas have numerous inserts of varying specularly and reflectance properties, corresponding to equipment and control layouts being investigated at the time of testing.

Testing was performed with the ambient lighting systems installed in the upper standoffs of both modules (fig. 3). All luminaires were fabricated from common "off-the-shelf" building products, with a lensed fluorescent luminaire installed in the HAB module (fig. 4) and an internal reflector fluorescent prototype deployed in the LAB module (fig. 5). While the HAB luminaire distributes light directly throughout the module's center volume, the LAB indirect prototype was designed to illuminate only the adjacent wall and ceiling rack surfaces, with those surfaces being utilized as secondary reflectors to illuminate the center volume (fig. 6).

The concept for the LAB prototype luminaire positions the reflector assembly several inches in front of a typical rack face to facilitate illuminance uniformity on the rack face. To move a rack for replacement or rear rack housekeeping, the lighting assembly is recessed into the standoff to provide rotational clearance (fig. 7). To optimize usage of the limited standoff face area, cabin air, audio, video, and data subsystems were integrated into the luminaire housing.

The illuminance meter utilized for measurements was the microprocessor and silicon photocell-based Minolta model T-1M, corrected for spectral response and incident angles. Zero-level calibration was established during setup prior to each data recording session. The Minolta luminance meter model LS-100 was employed for all luminance measurements. This is also a microprocessor-based spectral response corrected meter, with a  $1^\circ$  acceptance angle. All luminance measurements were taken utilizing Minolta's standard lamp calibration setting and do not reflect the 1.005 color correction factor recommended by the manufacturer for the installed lamp types. Luminance meter calibration was verified by measurements of a magnesium oxide sample of a known 97-percent reflectance.

## TESTS AND PROCEDURES

The desire to investigate a wide range of potential ambient lighting options and the concern with uniformity of rack face illumination led to the original installation of luminaires on both upper and lower standoffs (fig. 8). Preliminary evaluations of this configuration in both the HAB and LAB modules revealed serious problems with direct glare conditions for crewmembers accessing wall-oriented workstations as well as concerns with the ability to establish a vertical reference. As a result, the lower standoff luminaires were eliminated from further analysis.

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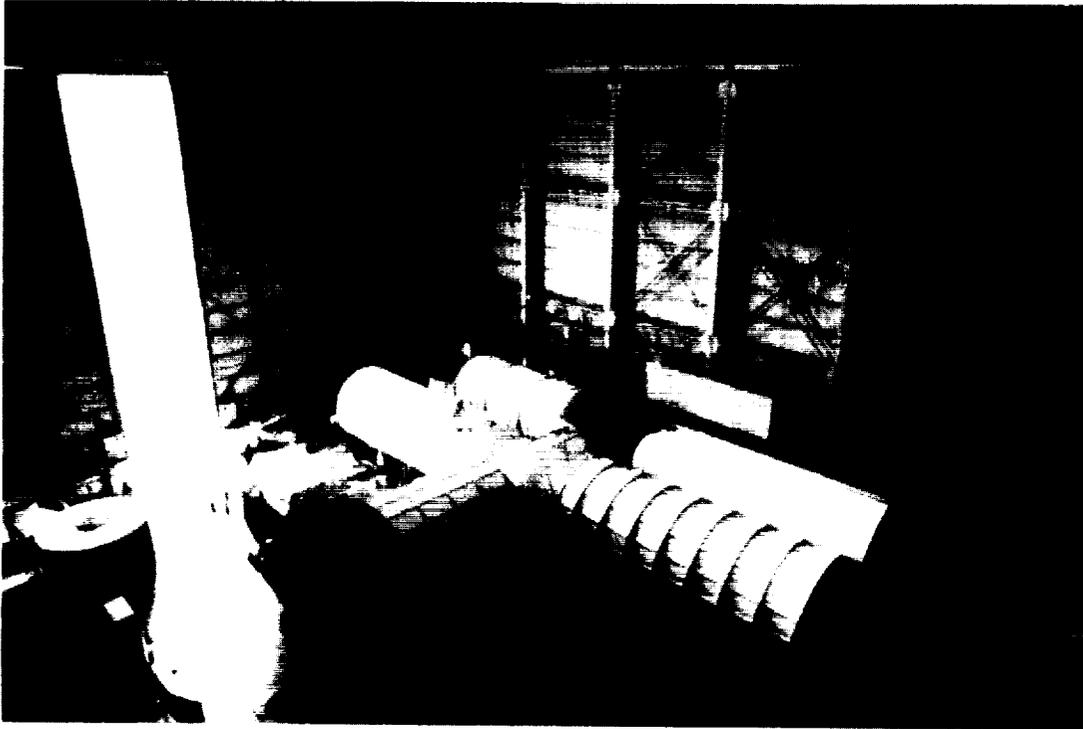


Figure 2. Exterior view of the full-scale mockup Space Station *Freedom* at MSFC shortly after completion.



Figure 3. (A) Interior view of the habitation module mockup used for testing. (B) Interior view of the U.S. laboratory module mockup used for testing.

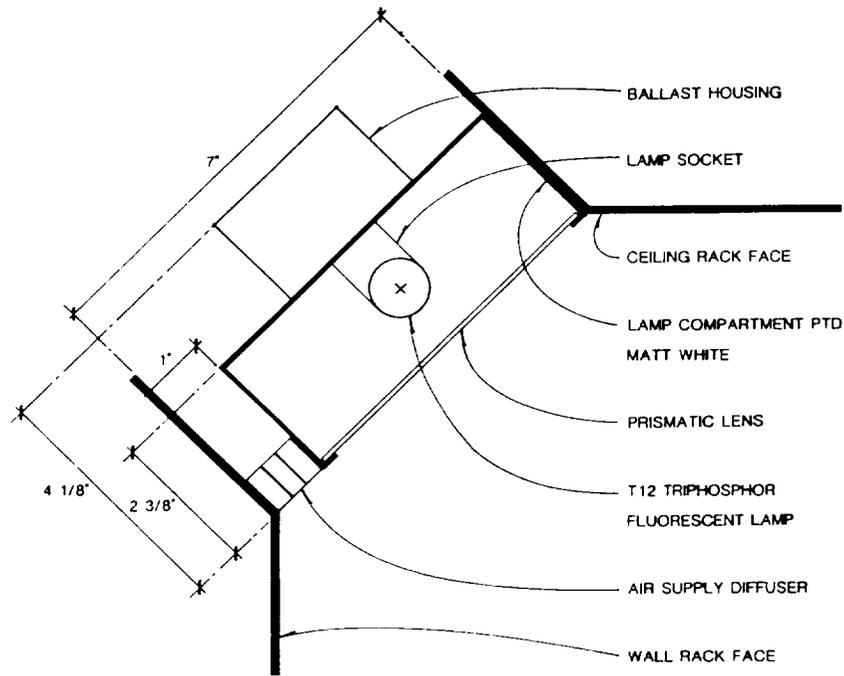


Figure 4. Detail of a typical direct luminaire installed in the upper standoff of the habitation module mockup.

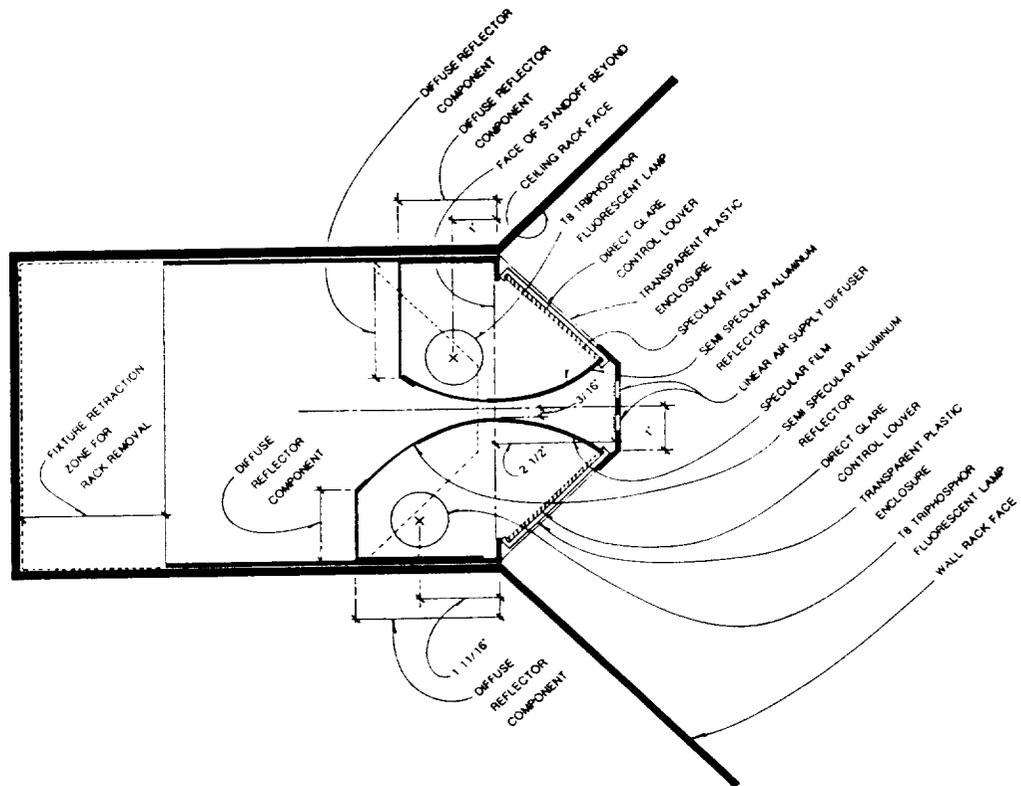


Figure 5. Detail of the indirect prototype luminaire installed in the U.S. laboratory module mockup.

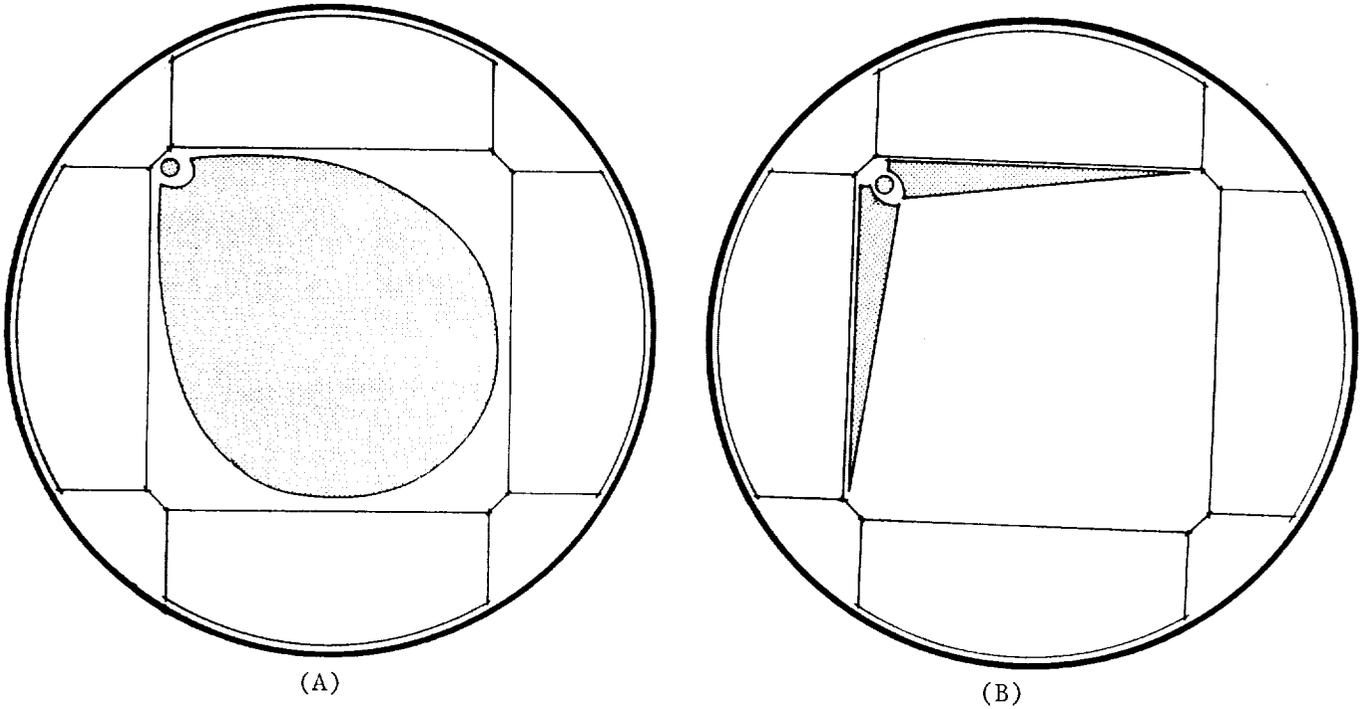


Figure 6. (A) Illuminance distribution concept of the direct luminaire. (B) Illuminance distribution concept of the indirect luminaire.

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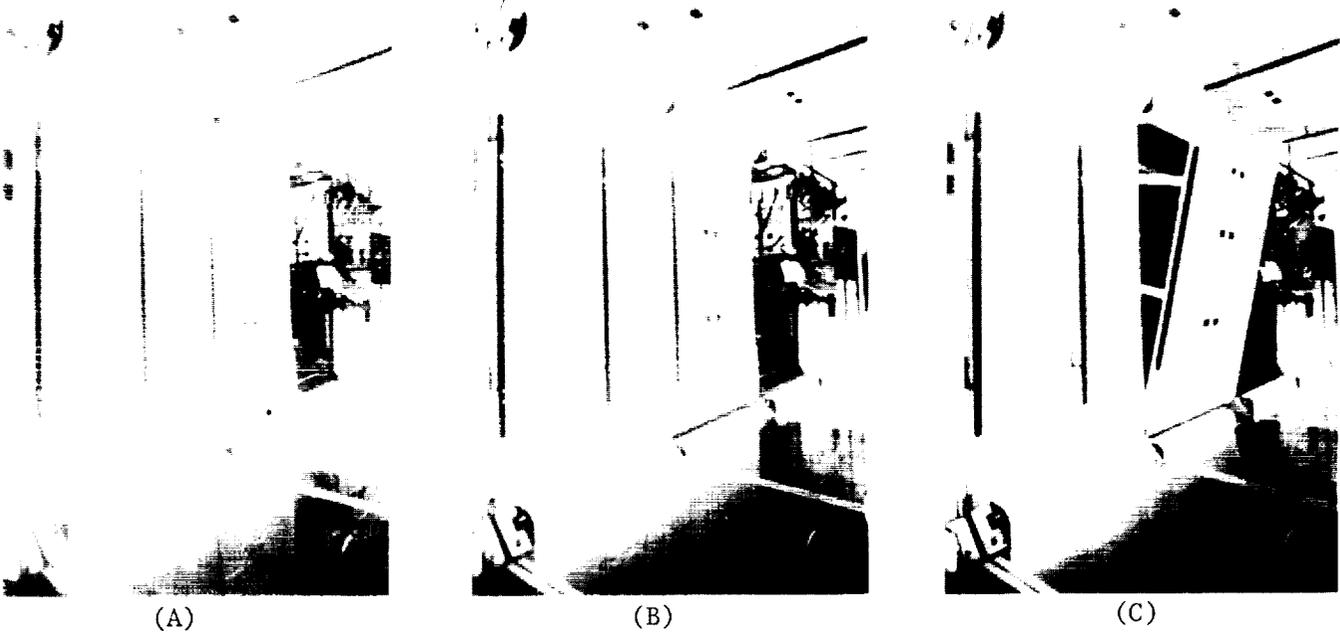
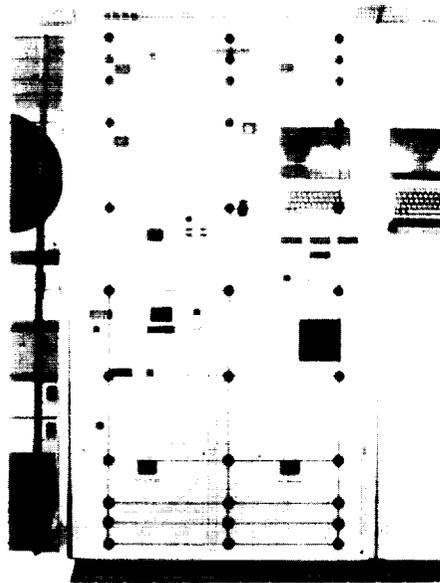


Figure 7. (A) Operational position of indirect luminaires installed in the LAB module. (B) Recessed position of the indirect luminaire to allow clearance for rack rotation. (C) Partial rotation of a typical payload rack demonstrating rack removal and replacement process.

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Figure 8. Indirect luminaires installed in the upper and lower standoffs of the LAB module mockup shortly after completion.



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Figure 9. Standard array of data points on a typical rack face.

Test procedures were standardized for data collection in both modules, with a typical array of data points established based on the dimensions of a double rack (fig. 9). Areas for data collection within the modules were selected to minimize the number of rack face inserts that exhibit varying specularly and reflectance properties. While predominately undifferentiated rack faces were selected for data acquisition, when data points fell on an insert, measurements were taken on the nearest adjacent uniform surface. Data were collected from a three-rack section near the center of each module on the assumption that it would be representative of conditions throughout the interior. Illuminance, luminaire luminance, and rack surface luminance were investigated for all test configurations.

Illumination data was recorded for both modules in two planes parallel to the floor: one with the standard array of data points 30 in above the floor plane and the second with the standard array 42 in above the floor. Three data sets were recorded for each test configuration: horizontal footcandles, vertical footcandles facing aft, and vertical footcandles facing port. Given the symmetry of the module architecture, luminaire layout, and surface reflectances, it was assumed that vertical illuminance data facing forward and starboard would not differ significantly from that recorded. Care was taken to minimize body shadow influence on measurements while uniform receptor orientation was maintained by utilizing a sensor mounting stand for all illuminance data recording. The 30-in data plane was selected to correspond with the accepted Earth-bound practice of measuring illuminance at the typical office 30-in work plane height as well as MSIS requirements. The 42-in data plane was selected as the geometric center of a module as well as to provide baseline data for comparison with the previous Boeing illumination study [6].

Luminaire luminance measurements followed the guidelines in the "IES Practical Guide to Photometry" [7]. For each test luminaire, data was taken in  $10^\circ$  increments from nadir to horizontal in planes parallel and perpendicular to the long axis of the luminaire. The luminous aperture was scanned for maximum and minimum values, with five additional readings taken at random locations for each  $10^\circ$  increment. For each reading, the meter was positioned approximately 57 in from the luminaire face to maintain a uniform sample area of  $1 \text{ in}^2$ . The average of these seven readings was then used to characterize the luminous aperture. In some oblique viewing orientations the luminous aperture was not visible to the meter. At other viewing angles the  $1^\circ$  acceptance angle encompassed part of the adjacent rack face as well as the luminaire's luminous aperture. For example, the luminous aperture of the LAB upright is not exposed to the meter at any point between nadir and horizontal in the parallel axis. In such instances data was not recorded.

Surface luminance measurements of each rack were recorded from a fixed meter position, resulting in incident viewing angles that ranged from approximately  $50^\circ$  to  $90^\circ$  and test distances ranging from 57 to 80 in. Additional data sets were obtained from a random point on a rack face, recording surface luminance for incident viewing angles between  $40^\circ$  and  $90^\circ$  in  $10^\circ$  increments at meter distances from roughly 54 to 84 in. This data shows a maximum 0.6-percent difference in observed luminance induced by the changes in viewing angle and distance, verifying the acceptability of the test procedure.

In the habitation module, three test configurations were investigated: every luminaire switched on, every second luminaire on, and every third luminaire on. With the variable photometric distribution possible using the prototype indirect luminaire, these same configurations were

investigated in the U.S. LAB module, but with significant variations. For each of the three luminaire spacings, data was recorded for the following conditions (fig. 10):

1. The up and downlight components both on, illuminating the ceiling and wall rack faces respectively
2. The uplight component on, illuminating only the ceiling surface
3. The downlight component on, illuminating only the wall surface.

Caution must be used in viewing and interpreting the included photographs as film, photographic paper, and halftone reproductions do not exhibit the same response as the human eye does to luminous contrast and the spectral composition of light sources [3]. The photographs are intended only to illustrate the test configurations under discussion.

## RESULTS AND DISCUSSION

Prior to reviewing the data generated by the different test configurations, the reader must be cautious of several possible fallacies inherent in this investigation. While efforts to conform to accepted industry standards were prevalent in setting up test and recording data, there remains some concern with the use of the full-scale mockup as a test installation. The initial intent of both the mockup and the installed luminaires was primarily for concept demonstration, with acceptable tolerances for design and production set accordingly. To meet both time and budget constraints, luminaires were designed and fabricated from readily available off-the-shelf components even though more expensive, longer-delivery, or custom-fabricated components would have better served a given function. Additionally, while protrusions and inserts on rack faces may mimic actual hardware layouts, they also have the potential to inject irregularities into the recorded data. The investigators have been conscious of these pitfalls and have made efforts to recognize and, where possible, minimize these aberrations throughout the data collection and analysis process. For example, shadows from a piece of surface-mounted equipment in the HAB module resulted in abnormally low readings for horizontal and vertical illumination at one data point in the 30-in data plane. This data point was noted in testing and eliminated from analysis.

Both horizontal and vertical illuminance measurements varied considerably from one test configuration to another, yet each configuration could be specifically designed to provide a minimum of 10 fc as required by MSIS STD-3000. One method of comparing test configurations, independent of measured intensities, is to compare various luminance and illuminance ratios produced by the configurations under consideration. For example, the ratio of maximum to minimum illumination in the 30-in plane will remain invariant for a test configuration regardless of intensities measured. Whether the luminaires operate at full intensity or are dimmed to some level, the configuration will yield luminance and illuminance ratios specific to that configuration and independent of actual illuminance and luminance data recorded.



A. LUD1: LAB module indirect up and downlight component luminaire spaced every rack.



B. LUD2: LAB module indirect up and downlight component luminaire spaced every second rack.



C. LUD3: LAB module indirect up and downlight component luminaire spaced every third rack.



D. LU1: LAB module indirect uplight component luminaire spaced every rack.

Figure 10. LAB module indirect luminaire test configurations.

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E. LU2: LAB module indirect uplight component luminaire spaced every second rack.



F. LU3: LAB module indirect uplight component luminaire spaced every third rack.



G. LD1: LAB module indirect downlight component luminaire spaced every rack.



H. LD2: LAB module indirect downlight component luminaire spaced every second rack.

Figure 10. LAB module indirect luminaire test configurations (continued).



### **Illuminance**

A review of the distribution of horizontal illumination (fig. 11) reveals little difference in uniformity between the direct and indirect test configurations. However, an increase in the luminaire spacing interval produces some decrease in the uniformity of horizontal illumination for all test configurations in both the 30-in and 42-in data planes. Due to the lack of directional control provided by the lens, the luminaire spacing in the direct system can be increased to every second rack without appreciably affecting uniformity. With the indirect system, the use of the ceiling as a diffusing surface allows the luminaire spacing interval to increase to every second rack in the up + downlight configuration and every third rack in the upright configuration without significantly altering uniformity. While a slight decrease in uniformity between the 30-in and 42-in data planes is apparent in all test configurations, the extrapolation of this trend to planes above 42-in could be undesirable in microgravity environment. With visual tasks also likely to occur above and below a 30-in work plane, it is possible that a continuing reduction in uniformity could affect performance of tasks occurring above the 42-in plane. Utilizing the ceiling as a diffuse secondary reflector should help maintain the uniformity of horizontal illumination in planes above 42-in. The higher max/min ratios produced by the second and third rack spaced downlight configurations are not unexpected given the test distances and angular relationships involved.

While not specified as a metric in MSIS, it seems important for the ambient system to illuminate the vertical as well as horizontal surfaces of objects in the center volume of a module. In a microgravity environment it is improbable that routine visual tasks in a module's center volume would be oriented only in a horizontal plane. A review of vertical illuminance recorded in both the long (facing aft) and short (facing port) module axis directions results in observations comparable to those discussed regarding the horizontal illuminance data. There appears little differentiation between the direct and indirect test configurations, while luminaire spacing has considerable influence on ambient vertical illuminance (fig. 12). Considering only the luminaire placement and test distances involved, one would expect a greater uniformity in vertical illumination facing aft than that observed facing port for the indirect test configurations. This seems to be a result of the impact of the visual cutoff louver on the luminaire's photometric distribution and the resultant direct illumination on some data points.

Some measure of illumination provided by the ambient lighting system is necessary through the center volume of a module to verify accommodation of noncritical visual tasks, but it seems more appropriate that both horizontal and vertical illumination be considered in multiple planes from floor to ceiling. While this would more closely relate to the flexible and changing use of this volume as well as the various body positions and viewing angles of the crew, it does not directly address the importance of producing surface luminances to maintain crew comfort and psychological well-being on long duration missions. Given this relationship, interior ambient lighting systems should be designed to produce a range of desired surface luminance distributions and intensities in addition to a specified number of footcandles in the center volume [8].

### **Surface Luminance**

In comparing surface luminance distributions, the different reflectances of ceiling, wall, and floor racks of the HAB and LAB mockups have been factored out to produce comparisons based on a common surface reflectance of 74 percent for all racks in both the modules.

The intensity, size, and position of luminances in a crewmember's field of view are central in determining the speed and nature of the physiological reactions necessary for visual assimilation [9]. As luminance ratios become extreme, transient adaptation times increase, veiling reflections on specular surfaces become obstructive, discomfort glare conditions become prevalent, and proper film or video exposure becomes problematic. Over the course of a typical work day, the speed and accuracy of performing visual tasks can be severely impaired.

Surface luminances of a module were examined as being roughly representative of the contrast present in the visual field when a crew member is oriented toward a specific interior surface versus being oriented on the long axis of the module (fig. 13). As with illumination, the single factor showing the greatest influence on uniformity of surface luminance is that of the luminaire spacing interval. As would be anticipated from the geometric relationship of the luminaires to the different cabin surfaces, the floor exhibits little variation in uniformity while wall and ceiling luminance ratios are most susceptible to changes in spacings. Only the single rack spacing configurations appear satisfactory when considering transverse (wall, floor, or ceiling) viewing orientations, with all two- and three-rack spacing configurations producing ratios that border on or exceed the MSIS maximum of 10:1. When considering long axis viewing where all surfaces appear in the

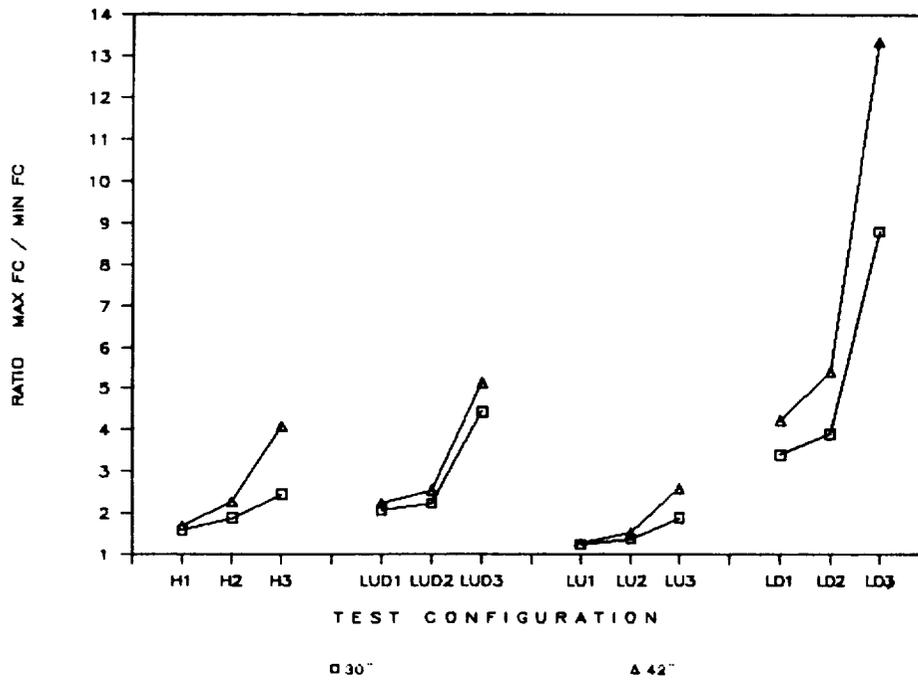


Figure 11. Horizontal illuminance uniformity: max/min ratio of horizontal illuminance in the 30- and 42-in data planes.

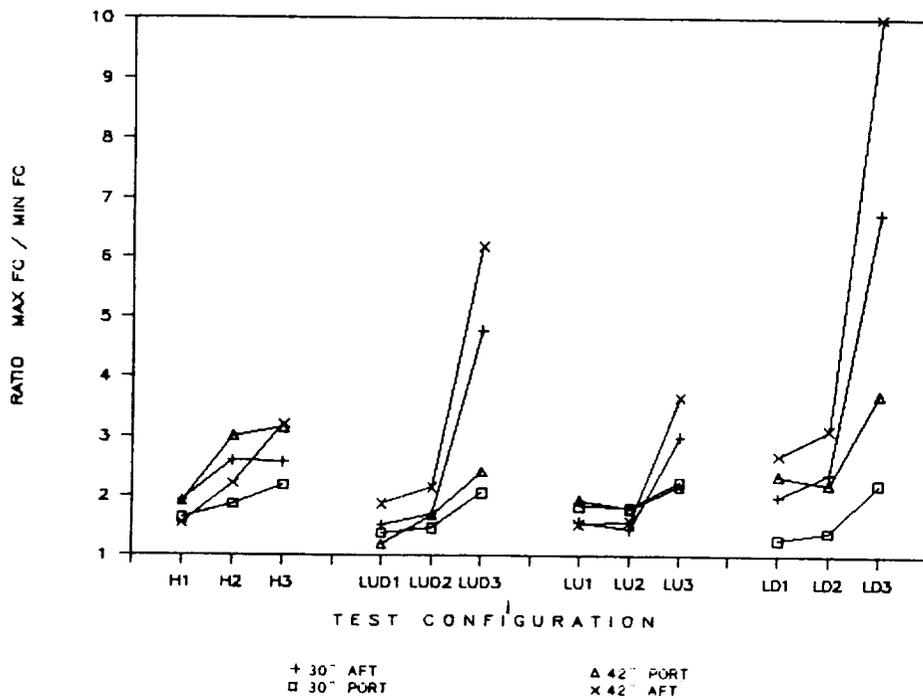


Figure 12. Vertical illuminance uniformity: max/min ratio of vertical illuminance in the 30- and 42-in data planes.

visual field, only the HAB single rack luminaire spacing configuration and the LAB single rack up + downlight configuration come close to meeting this specification.

These relationships generally hold true when individual rack faces are considered. The smaller visual field subtended while engaged at a typical workstation was approximated by considering the luminous distribution of a single rack face. By evaluating the racks with integral luminaires on, only the greatest luminance ratios for individual rack faces are compared (fig. 14). Racks with integral luminaires off between racks with integral luminaires on appear quite uniform due to the distances and geometries involved. They are within the acceptable luminance ratio limits and were not graphed. Only the HAB single-rack spacing configuration and the LAB single rack up + downlight configuration yield individual rack face luminance distributions with a max/min ratio less than 10:1.

With the established need to maintain a vertical visual orientation in a micro gravity environment, surface luminances could be key elements in providing the visual cues necessary to establish a vertical reference. In comparing the average surface luminance of the upper one-quarter module with corresponding data for the lower one-quarter module, it was found no test configuration generated luminance ratios significantly greater than 3:1, which is probably not enough contrast to establish a vertical reference. Investigation then focused on the possibility that small areas of increased surface luminance in the upper and lower quadrants would yield greater contrast. The average maximum luminance (average of five highest adjacent surface luminance measurements) for the upper quadrant was compared with the average maximum luminance of the lower quadrant (fig. 15). The average maximum luminance ratios were significantly greater than those produced by comparing average surface luminances, with all the indirect test configurations demonstrating a greater upper/lower luminance ratio than the direct test configurations. With the lack of an established lower contrast threshold required to maintain a vertical reference, it remains unclear if the direct test configurations provide surface luminance distributions necessary to maintain orientation. In considering the entire visual field, luminaire luminance could play a pivotal role in this orientation process [10], however, it should be kept in mind that increases in the upper/lower module luminance ratio to achieve a vertical reference will also accentuate problems with direct glare and veiling reflections.

## **Luminaire Luminance**

While interior surface luminances are central to the consideration of transient adaptation, direct glare, and CRT reflections, often the increased luminance of the luminaire aperture produces a ratio of luminaire luminance and adjacent surface luminance that becomes the most critical element affecting these habitability issues.

For initial comparison, the maximum luminaire luminance in the parallel and perpendicular viewing planes was related to the average luminance of two 1-ft-wide surface strips adjacent to the luminaire, one along the wall rack and the other on the ceiling rack (fig. 16). This comparison assumes the surface luminance of the adjacent racks will vary little with changes in viewing angle. While no direct illumination test configuration falls below the MSIS maximum of 20:1, the indirect single rack up + downlight configuration is acceptable in both the parallel and perpendicular viewing orientations. Additionally, several other indirect test configurations conformed to the MSIS standard when considering only perpendicular viewing angles. With a custom louver designed for

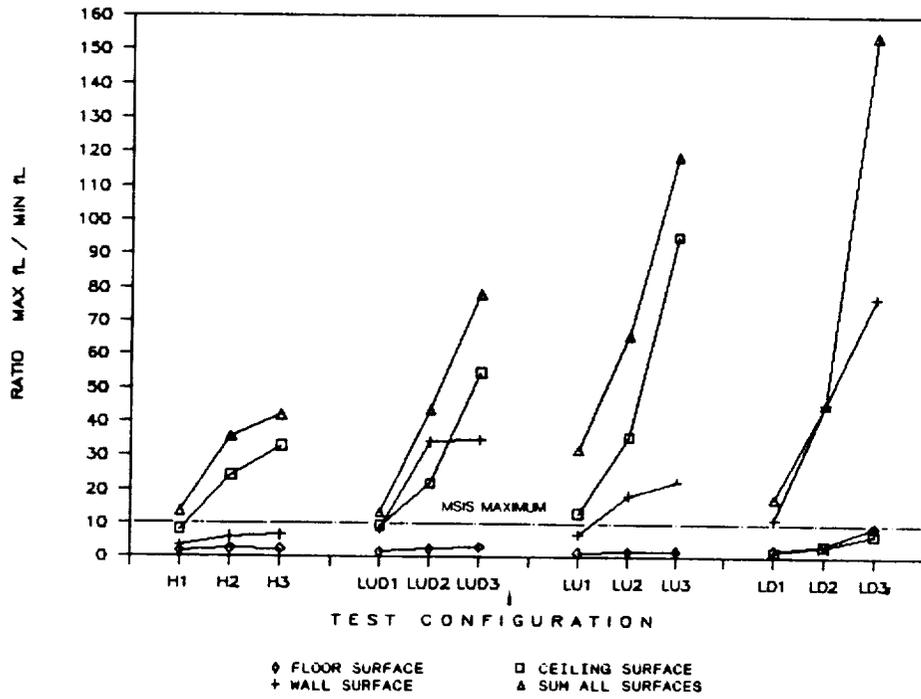


Figure 13. Module surface luminance: max/min luminance ratio of a module's interior surfaces.

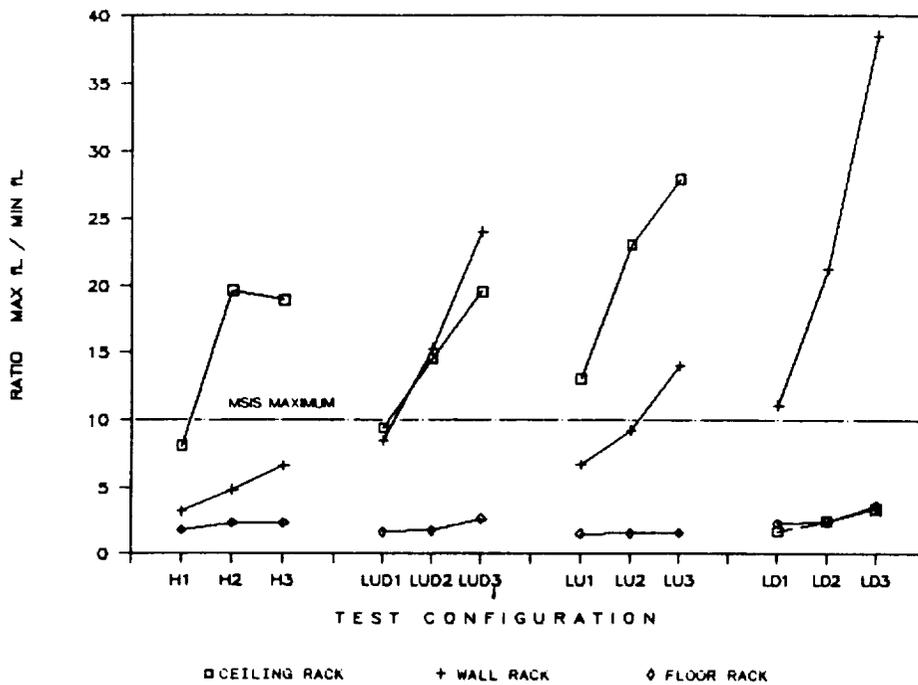


Figure 14. Rack face illuminance: max/min luminance ratio of an individual rack face.

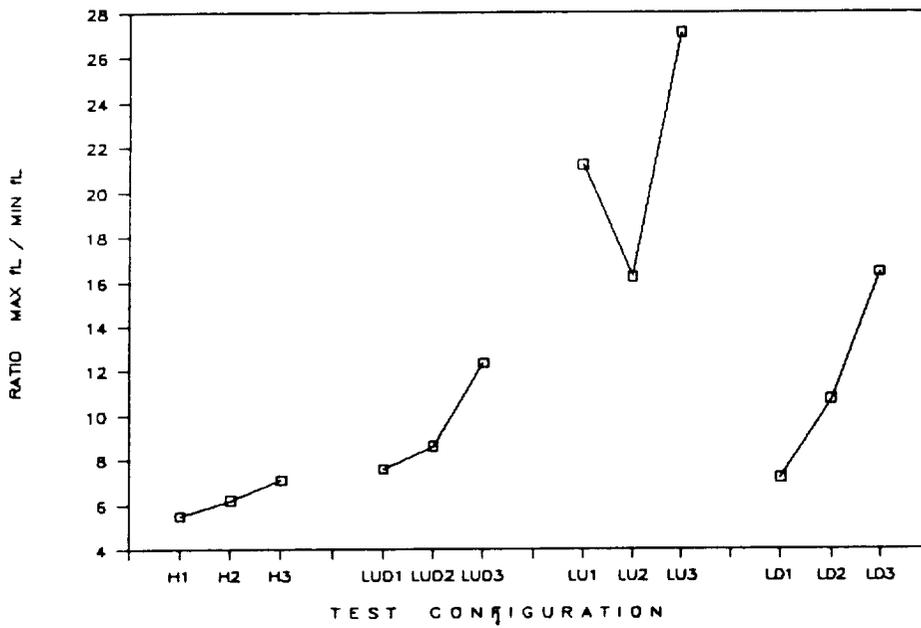


Figure 15. Vertical orientation: upper module/lower module average maximum interior surface luminance ratios.

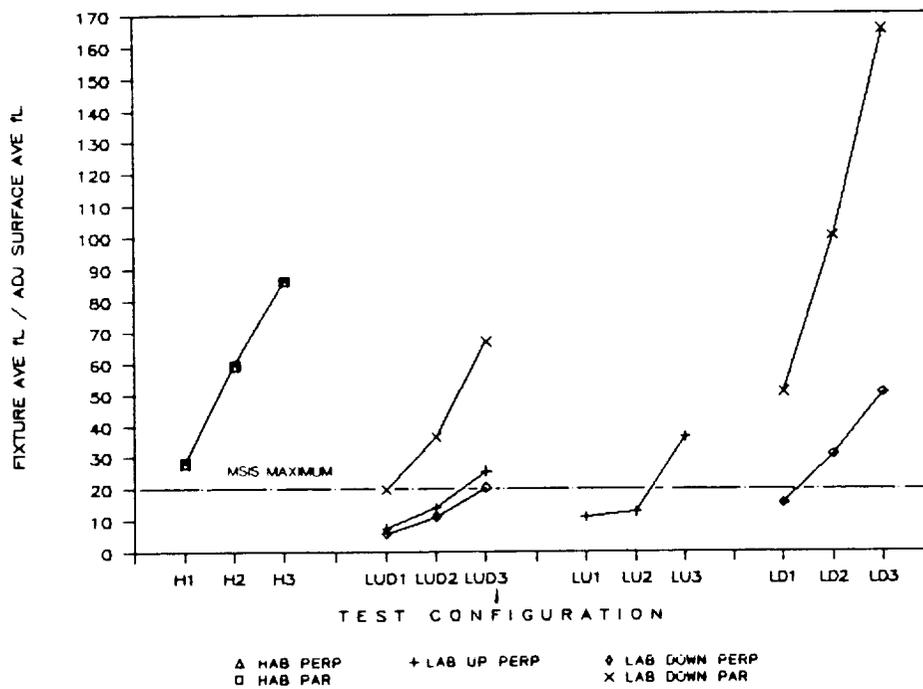


Figure 16. Luminaire and adjacent surface luminance: ratio of the maximum luminaire aperture luminance and average adjacent surface luminance.

visual cutoff in both the parallel and perpendicular planes, it would be anticipated that parallel axis luminaire/adjacent surface luminance ratios would approximate those of the perpendicular plane.

Due to the behavior of rack faces as nearly uniformly diffusing surfaces, interior surface luminance can generally be evaluated independently of viewing orientation. The directional intensity distribution of luminaires and the nonstandard viewing orientations of a microgravity environment combine to necessitate that a detailed consideration of luminaire luminance requires notation of the specific viewing angle. Readings taken at 10° increments both parallel and perpendicular to the luminaire's long axis were related to the average luminance of a 1-ft surface strip of both adjacent wall and ceiling racks, resulting in a viewing orientation specific luminance ratio.

A comparison of the HAB module direct luminaire single rack spacing configuration and the LAB module single rack up+downlight configuration is representative of an orientation specific luminaire/adjacent surface luminance ratio analysis (fig. 17). The direct luminaire yields ratios that are less than the MSIS maximum of 20:1 only for 70° and 80° viewing angles in the parallel axis, with no viewing angle in the perpendicular plane conforming to the standard. In the perpendicular plane, the indirect luminaire closely matches the adjacent rack surface luminance from the 20° through 60° viewing angles, and is well below the MSIS maximum luminance ratio in this viewing range. While size, spacing, and blade angle of the visual cut off baffle work well to minimize luminaire luminance at these angles, they allow the observer unobstructed visual access to the luminance of the reflector/lamp assembly at the upper and lower viewing ranges. Similar problems exist for most viewing angles in the parallel plane: the louver geometry does not provide a visual cutoff in this axis, therefore yielding unacceptably high luminaire/adjacent surface luminance ratios. A custom-designed cutoff louver should bring luminance ratios in these viewing directions more in line with values found in the 20° through 60° zone of the perpendicular axis.

In reviewing the viewing angle specific luminaire/adjacent surface luminance ratios, it is first noticeable that both the direct and indirect test configurations produce distinctive "signatures" or patterns of luminance data (figs. 18 and 19). While the luminaire luminance remains constant, the adjacent surface luminance decreases with a reduction in the interreflected illuminance component when luminaire spacing increases to every second and third rack test configurations, corresponding to definite increases in luminaire/adjacent surface luminance ratios.

## CONCLUSIONS

Results of existing behavioral research in illumination indicates that perceptual qualities of an enclosure can be influenced by the pattern of illumination within the space. Feelings of spaciousness, perceptual clarity, relaxation or tenseness, and public or private spaces, among others, appear to be related to different patterns of surface luminance. The LAB module prototype indirect ambient illumination system allows a crew to alter surface luminance distribution within an enclosure, thus enabling them to modify perceptual lighting cues over the course of a mission to match crew preference. Coupled with a dimming system, this approach provides the maximum degree of flexibility and user control over one aspect of the interior environment that will be critical to habitability on long duration missions.

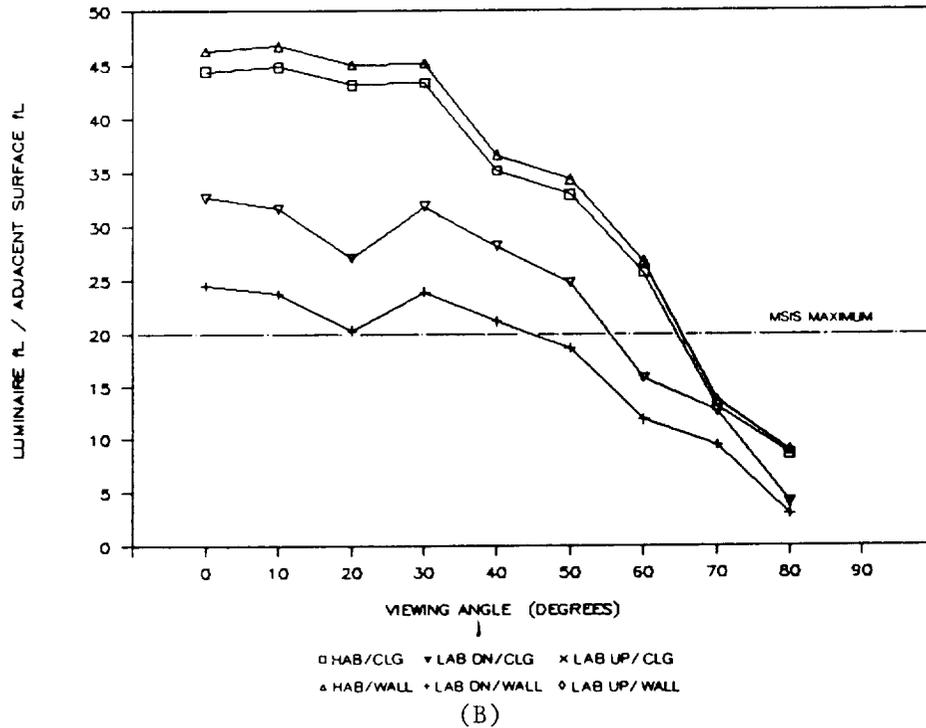
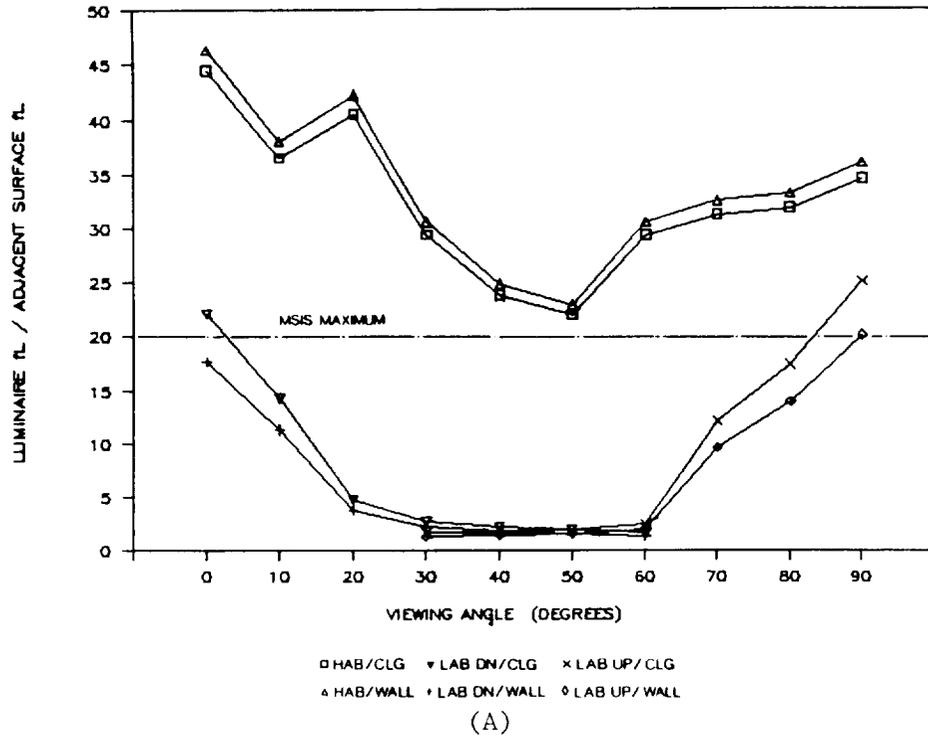
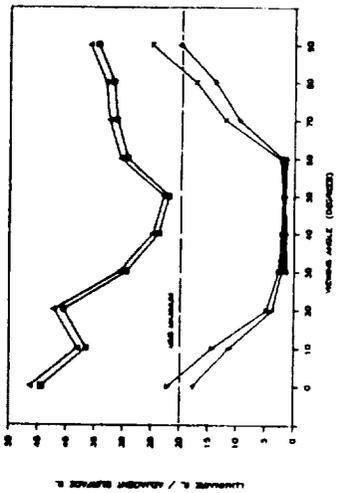
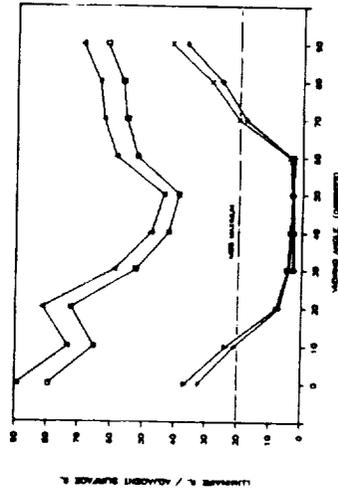


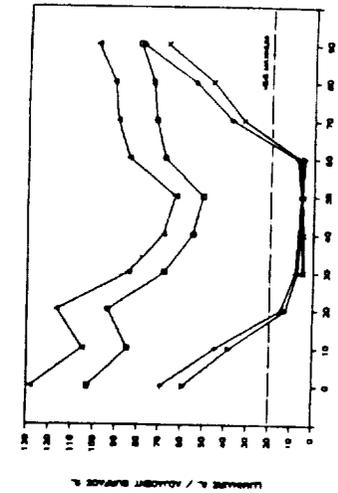
Figure 17. Orientation specific luminaire and adjacent surface luminance: (A) Ratio of the maximum luminaire aperture luminance and average adjacent surface luminance for viewing angles from nadir to horizontal in the perpendicular plane. (B) Ratio of the maximum luminaire aperture luminance and average adjacent surface luminance for viewing angles from nadir to horizontal in the parallel plane.



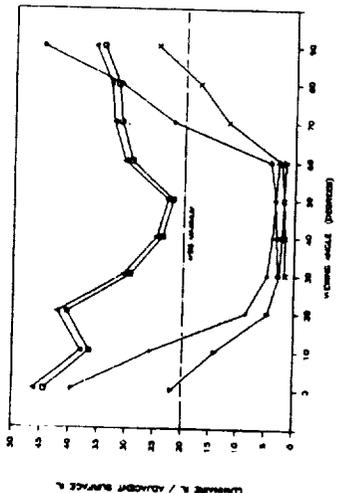
A. LUD1: LAB module indirect up and downlight component luminaire spaced every rack.



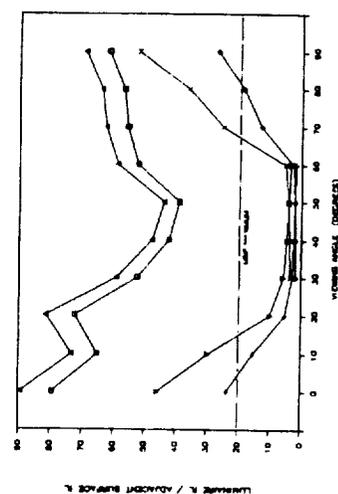
B. LUD2: LAB module indirect up and downlight component luminaire spaced every second rack.



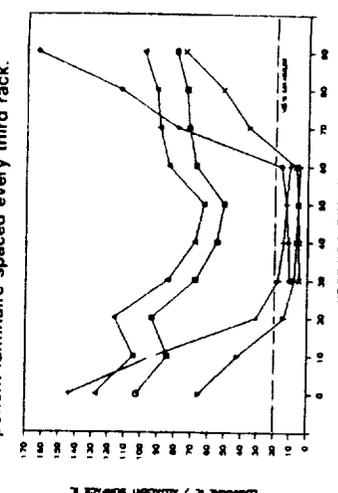
C. LUD3: LAB module indirect up and downlight component luminaire spaced every third rack.



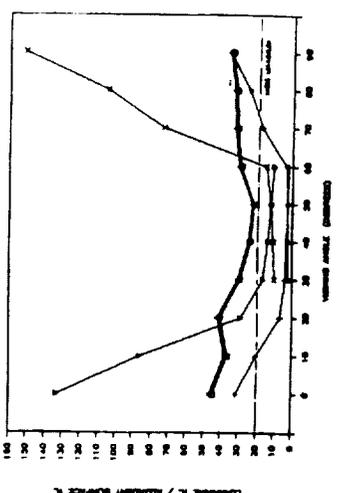
D. LUD1: LAB module indirect uplight component luminaire spaced every rack.



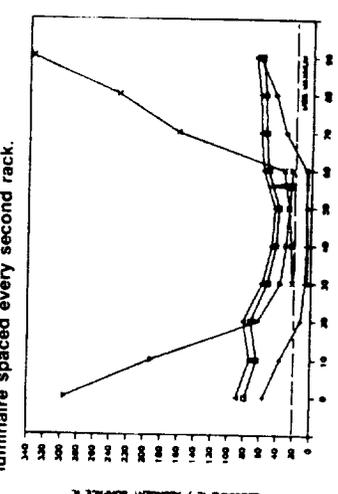
E. LUD2: LAB module indirect uplight component luminaire spaced every second rack.



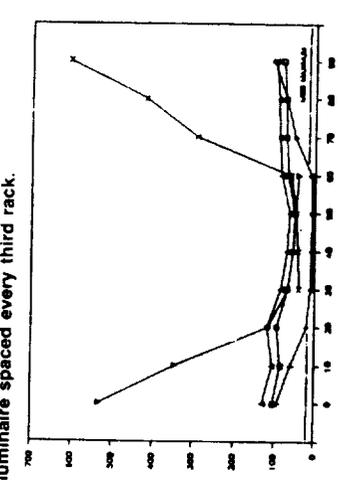
F. LUD3: LAB module indirect uplight component luminaire spaced every third rack.



G. LDI1: LAB module indirect downlight component luminaire spaced every rack.



H. LDI2: LAB module indirect downlight component luminaire spaced every second rack.



I. LDI3: LAB module indirect downlight component luminaire spaced every third rack.

Figure 18. Orientation specific luminance and adjacent surface luminance: Ratio of the maximum luminaire aperture luminance and average adjacent surface luminance for viewing angles from nadir to horizontal in the perpendicular plane.

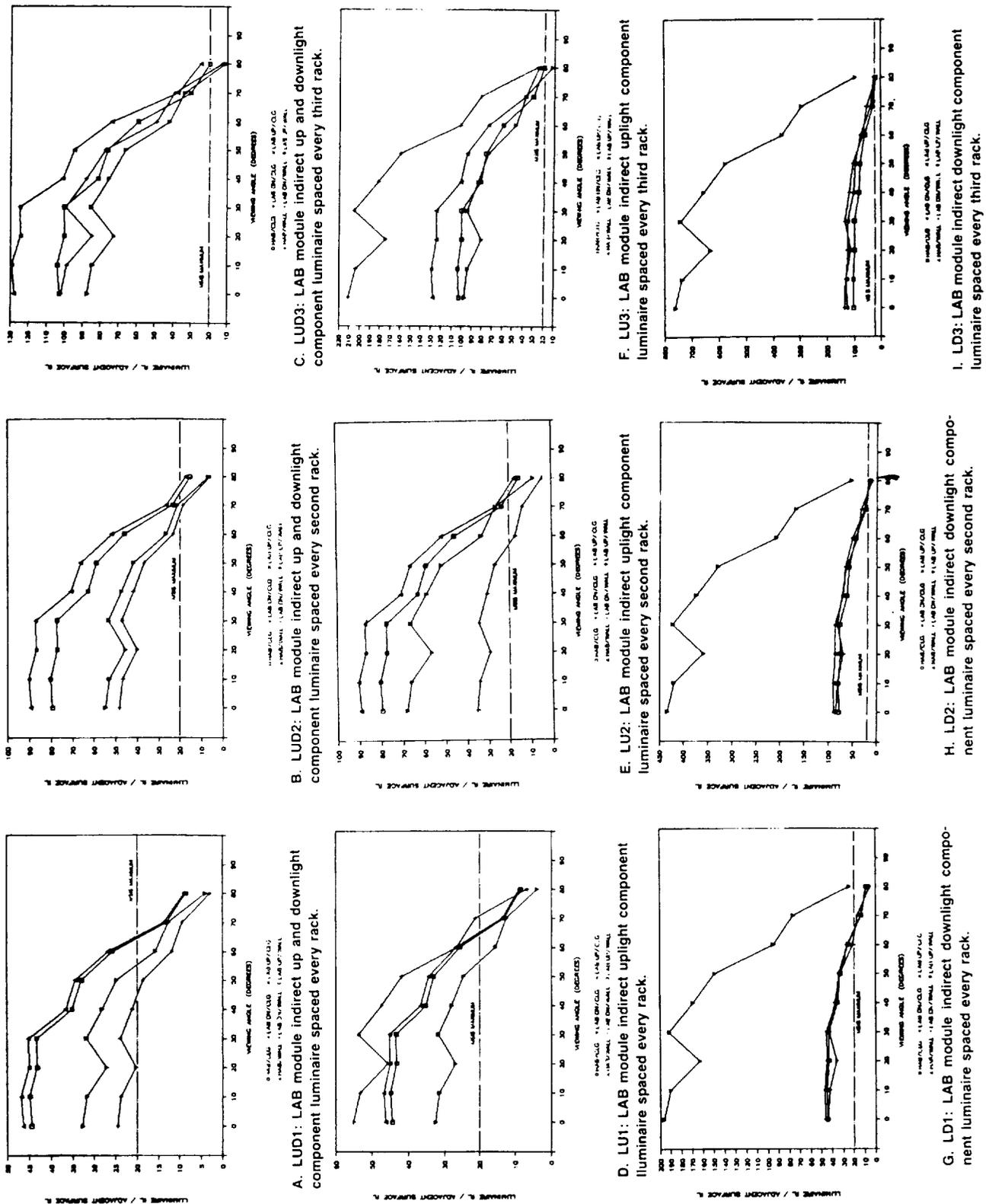


Figure 19. Orientation specific luminance and adjacent surface luminance: Ratio of the maximum luminance aperture luminance and average adjacent surface luminance for viewing angles from nadir to horizontal in the parallel plane.

A direct illumination system with dimming control only allows user modification of luminous intensity, without the ability to alter patterns of distribution. While adequate to provide the minimum required footcandles on a horizontal plane, the direct ambient test configurations produced greater luminaire luminances and greater contrasts between luminaire luminance and rack surface luminances than the indirect test configurations. These factors combine to raise serious problems with direct glare, veiling reflections on consoles, and taxing repetitive visual adaptations to luminous extremes in the visual field.

A review of the effects of luminaire spacing on luminance distribution suggest that luminaires providing ambient lighting should be spaced at each rack interval. As luminaire spacings increase to every second or every third rack, increasingly excessive luminance ratios on module surfaces result. Although not as pronounced, increased spacings also demonstrate a decrease in the uniformity of horizontal and vertical ambient illumination in the module's center volume. While existing test configurations involved luminaires that effectively spanned the full rack width, additional studies should investigate the possibility of using shorter luminaires to achieve comparable results and to determine the effects of their position relative to a rack face.

While each test configuration can be designed to provide the current MSIS minimum requirement for ambient illumination, only those direct and indirect test configurations with luminaires spaced at each rack were found in compliance with current MSIS standards for interior surface luminance ratios. While several indirect test configurations fell within the allowable limits for luminaire/adjacent surface luminance ratios, only the indirect prototype providing both ceiling and wall illumination met all the standards for illuminance and luminance of ambient lighting systems as currently defined in the MSIS.

Concern exists regarding the time required to recess the indirect prototypes in the LAB module out of the rotational path required for rack replacement or rear rack maintenance functions. While the degree of inconvenience this represents is largely a function of the frequency of these operations, the additional luminaire motion requirement does present another set of mechanical parts that may fail over the expected life of the space station. Subsequent investigation should focus on possible stationary luminaire configurations to yield an indirect illumination distribution with similar user control options.

The investigation of luminance and illuminance distributions of ambient lighting systems cannot be entirely divorced from the specific hardware assemblies that generate a given distribution. Variations of different lenses, reflector shapes, and louver geometries all affect photometric distributions. Any evaluation of a lighting system is incomplete without also considering the interaction of task and ambient illumination subsystems, as well as the interaction of the lighting system and interior surface finishes. To avoid visual chaos and maintain the desired illuminance and luminance distributions, higher fidelity luminaire models should be pursued with the interactions of both task and ambient subsystems considered in the context of interior finish options.

After reviewing existing space qualified light sources [11,12,13,14], investigation to date has utilized only fluorescent lamps in the luminaire mockups. Advances in technology in recent

years have the potential to provide more compact, lighter weight, more efficient sources of illumination. New fluorescent, high-intensity discharge, electroluminescent, radioluminescent, and light-emitting diode technologies all should be reviewed for potential applications in the manned space program.

The design specifications themselves warrant review and updating. The illumination sections of NASA-STD-3000 vol. IV remain an outdated mix of prescriptive and performance specifications. The use of a prescriptive specification inhibits innovative problem-solving and utilization of new advances in technology. Ambiguous, subjective, nonbinding language currently exists, with phrases such as "where possible," "when required," "perceptible," and "shall be minimized" employed without clear technical definition. In several cases, specifications reflect common Earth-bound metrics without acknowledging modifications to accommodate a microgravity environment. Illumination requirements do not define direction or limits of uniformity and refer to a standard 30-in Earth-bound seated work plane height. All luminaire luminance standards are identified without regard to viewing orientation. This lack of specificity in most cases does not meet current industry standards for Earth-bound projects and has made the task of evaluating the mockups for MSIS compliance difficult and subject to considerable interpretation.

Research recently completed or currently in progress indicates strides are being made in understanding the interaction of light and human physiological as well as psychological and perceptual systems [15]. Investigation of the role light plays in circadian rhythms and seasonal affective disorder (SAD) is among some of the current research that promises to have immediate impact on the MSIS as they are currently written. Over the past 10 years metrics have been developed or applied in the lighting industry in an attempt to quantify several of the human factor issues critical in lighting design. In North America, these include:

Visual Comfort Probability (VCP): an evaluation of discomfort glare resultant from luminaires directly in the field-of-view.

Equivalent Sphere Illumination (ESI): a determination of the effectiveness of a lighting system in controlling veiling reflections.

Relative Visual Performance (RVP): an assessment of a lighting system relative to the speed and accuracy of performing a visual task.

Currently absent from discussion in the MSIS documents, these metrics and their European counterparts warrant review to determine their applicability for lighting design for manned spacecraft.

While recent research needs to be incorporated into the specifications, there remain significant gaps in current knowledge concerning the interaction of light and man. The ultimate measure of the effects of illumination systems on habitability is man, not a photometer, and much research remains to be done with human subjects. Threshold cues necessary to acquire and maintain vertical orientation need to be established. The pioneering research at Pennsylvania State University in the 1970's [2] utilizing factor analysis and multidimensional scaling to interpret human subjective responses to lighting installations requires review, with the goal of applying appropriate methodologies to guide lighting design for man's exploration of space. The additional support of Space

Station *Freedom* by the European Space Agency and the National Space Development Agency of Japan should lead to studies investigating possible cultural differences in the human response to lighting, particularly regarding subjective impressions.

With an increased understanding of the requirements for long-duration manned missions and potential human habitation of space, NASA can also play a leadership role in helping direct the allocation of critical resources to qualitatively satisfy the increasing needs of human shelter on Earth.

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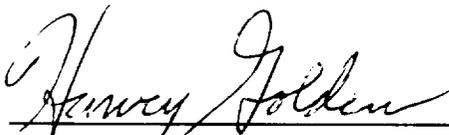
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## APPROVAL

### ILLUMINANCE AND LUMINANCE DISTRIBUTIONS OF A PROTOTYPE AMBIENT ILLUMINATION SYSTEM FOR SPACE STATION *FREEDOM*

R.C. Mullican and B.C. Hayes

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



*for* CAROLYN S. GRINER

Director, Mission Operations Laboratory



